Draft
Concept Paper
Specifications For Commercial Refrigeration

I. Overview

High global warming potential (GWP) greenhouse gas (GHG) emissions are expected to grow substantially over the next several decades, primarily from the use of ozone-depleting substance (ODS) substitutes, such as hydrofluorocarbons (HFCs). The introduction of ODS substitutes to the refrigeration and air-conditioning (RAC) sectors is the major driver of this growth. Additionally, although they are being phased out, ODS (many of which have high GWPs) are currently employed in older RAC equipment, and recycled refrigerants may be used indefinitely in old equipment. ODS and HFC refrigerants are relatively inexpensive, often comparable in price, and readily available.

There are two significant sources of GHG emissions from stationary RAC systems, direct emissions (high GWP refrigerant emissions due to leaks, routine servicing, intentional or accidental venting, and end-of life refrigerant reclamation) and indirect emissions (CO_2 emissions resulting from energy generated to operate the RAC equipment). Because direct and indirect GHG emissions are closely linked in the RAC sectors, lifetime CO_2-equivalent GHG emissions, or Life Cycle Climate Performance (LCCP), must be considered when examining low-GWP refrigerants or systems with reduced refrigerant leakage, but increased energy requirements.

II. Background

<u>Need for Regulations:</u>
The California Global Warming Solutions Act of 2006 (AB 32) requires the Air Resources Board (ARB) to reduce GHG emissions in California, with the overall goal of restoring emissions to 1990 levels by the year 2020. Emissions from refrigeration and air conditioning systems are categorized as direct refrigerant emissions (typically high-GWP ozone depleting substances [ODS] or hydrofluorocarbons [HFCs]) and indirect emissions (CO_2-equivalent emissions resulting from energy use)

<u>Current Control Practices</u>

Emission control practices do not currently exist for commercial refrigeration systems. For ODS systems containing more than 50 lbs of refrigerant, there are federal leak repair requirements (see below), but these are not restrictive enough, with allowable leak rates of up to 35% per year, and they are unenforced.

Current US Regulatory Requirements

Currently, only ODSs are regulated under Sections 608-609 of the Clear Air Act Amendments and SCAQMD Rule 1415, described in more detail below. Again, enforcement of existing rules is weak to non-existent.

Sections 608 and 609 of the Clean Air Act Amendments (CAAAs)

Systems containing more than 50 lbs of an ODS have some sales, record-keeping/reporting, technician and equipment certification, recovery/reclamation, and emissions restrictions (leak rates from commercial or industrial process systems over 35% per year require repair within one month).[1] HFCs are only subject to "no venting" under sections 608 and 609 of the CAAAs.

Rule 1415

Rule 1415 is a SCAQMD reporting rule for large ODS systems; RAC systems containing more than 50 lbs of an ODS must report annual usage. ARB has discussed the possibility of electronic reporting with the SCAQMD, which could potentially be extended to the whole state.

Types of Commercial Refrigeration Systems

Retail food refrigeration includes refrigerated equipment found in supermarkets, convenience stores, restaurants, and other food service establishments.[2] This equipment includes small reach-in refrigerators and freezers, refrigerated display cases, walk-in coolers and freezers, and large parallel systems.[3] Charge sizes range from 6 to 1,800 kilograms, with system lifetimes of 15 to 20 years.[4]

Direct Expansion (DX) Systems

Convenience stores and restaurants typically use stand-alone refrigerators, freezers, and walk-in coolers.[5] In contrast, supermarkets usually employ large direct expansion (DX) systems that connect many display cases to a central condensing unit by means of extensive piping.[6] Because the piping required for connection of all the cases can be miles long, these systems may contain very large refrigerant charges, on the order of thousands of pounds.[7]

The prototypical central supermarket system includes various refrigerated and frozen food display cases, connected to a central refrigeration system, typically

[1] Owners or operators must either repair leaks within thirty days from the date the leak was discovered, or develop a dated retrofit/retirement plan within thirty days and complete actions under that plan within one year from the plan's date. However, for industrial process refrigeration equipment and some federally-owned chillers, additional time may be available.

[2] U.S. High GWP Emissions 1990-2010: Inventories, Projections and Opportunities for Reductions, EPA 000-F-97-000, June 2001.

[3] U.S. High GWP Emissions 1990-2010: Inventories, Projections and Opportunities for Reductions, EPA 000-F-97-000, June 2001.

[4] U.S. High GWP Emissions 1990-2010: Inventories, Projections and Opportunities for Reductions, EPA 000-F-97-000, June 2001.

[5] U.S. High GWP Emissions 1990-2010: Inventories, Projections and Opportunities for Reductions, EPA 000-F-97-000, June 2001.

[6] U.S. High GWP Emissions 1990-2010: Inventories, Projections and Opportunities for Reductions, EPA 000-F-97-000, June 2001.

[7] U.S. High GWP Emissions 1990-2010: Inventories, Projections and Opportunities for Reductions, EPA 000-F-97-000, June 2001.

located in a mechanical equipment room or a rooftop enclosure. The common DX central refrigeration system consists of several sets of rack mounted compressors that independently serve a portion of the refrigeration load in the store. Often there are two racks for medium temperature, fresh food loads and two racks for low temperature, frozen food loads, but the exact configuration varies depending on the store size and other factors.

Traditionally, the long runs of liquid and suction vapor lines connecting the display cases with the central compressor system in the DX configuration have been a source of refrigerant leaks, due to the large number of threaded tubing joints, mechanical vibration, and the significant movement caused by thermal expansion during hot gas defrosts.[8] In California, the average DX system charge size is estimated to be approximately 2800 lbs with an annual leak rate of approximately 30%.[9]

Standalone Equipment

Supermarkets also utilize various self-contained refrigerators that are similar to domestic refrigerators; however, significant differences between domestic refrigerators and their self-contained commercial counterparts exist, including the range of refrigerated storage volumes, refrigeration capacities, the range of refrigerants used, and applicable energy efficiency regulations.[10]

Standalone equipment has not achieved the energy efficiency of domestic refrigerators, partly because test methods, regulations, or voluntary programs such as Energy Star do not exist for open and closed standalone cases or vending machines.[11] Because standalone compressors are not energy efficient and reject heat indoors, they compete with ambient heating and air conditioning (A/C) as well as contribute to warm air infiltration into refrigerated cases in many retail food establishments.

<u>Types of Refrigerants Employed</u>

Prior to the Montreal Protocol, CFC-12 (GWP ~10,600), R-502 (CFC/HCFC blend, GWP ~5490), and HCFC-22 (GWP ~1700) were the refrigerants used in commercial refrigeration systems.[12] As the CFC phase-out date passed, a complicated transitional regime of refrigerants emerged that still includes CFC-12 and CFC-502 from some existing equipment, along with HCFC-22, HCFC-22

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[8] Arthur D. Little, Inc., Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant, and Fire Protection Applications, Final Report to the Alliance for Responsible Atmospheric Policy, March 21, 2002.

[9] Estimates of general DX systems leak rates range from 15% for a “best-case” new installation to 30% or more for older systems (USEPA [reference, above], ARAP presentation to ARB, 2006, Denis Clodic presentation to ARB, 2007).

[10] Arthur D. Little, Inc., Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant, and Fire Protection Applications, Final Report to the Alliance for Responsible Atmospheric Policy, March 21, 2002.

[11] US DOE began the rulemaking process to develop test methods for some categories of standalone equipment (primarily vending machines) in late 2006.

[12] Arthur D. Little, Inc., Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant, and Fire Protection Applications, Final Report to the Alliance for Responsible Atmospheric Policy, March 21, 2002.

based blends, and HFC blends that replace CFC-502, including R404A and R507 (GWPs ~3300).[13]

Most existing retail food systems are currently retrofitted with HCFC-based blends, although HFC blends are also used.[14] New retail food equipment relies on HFC blends such as R-404A and R-507, although R502 is still used in some retail food establishments.[15,16]

Today, approximately 50% of retail food establishments use refrigerant blends containing HCFC-22 and 50% use R404A and R507A.[17] The change from HCFC-22 to HFC-containing blends is projected to cause GHG emissions from commercial refrigeration to increase in the future beyond what would be expected from continued HCFC-22 use, because the GWPs of the replacement HFCs are almost a factor of two higher than that of HCFC-22.

III. Emissions and Banks, Trends

CA Inventory: Preliminary Estimates from Denis Clodic/ARMINES

DX Systems, Direct Emissions

There are currently about 3,360 supermarkets in California, with 3-5 DX systems per store. Estimated emission rates are 30% per year per system. Total DX system emissions in California are estimated to be ~2.7 MMTCO$_2$E.

Banked refrigerant is estimated to be ~7.5 MMTCO$_2$E, which can be thought of as the total emission potential for existing DX systems in California.

Growth rate of ODS substitutes in the retail food refrigeration end-use category is estimated to be about 2%, which basically tracks California population growth.

DX Systems, Indirect Emissions[18]

Auxiliary components account for ~40% and compressors account for ~60% of DX energy consumption for all supermarkets in California. Energy consumption from DX systems in California is about 5.4 TWh/yr, which is about ~2.3 MMTCO2E (using a conversion factor of ~890 lbs CO$_2$E/MWh, accounting for California's energy mix).

[13] Arthur D. Little, Inc., Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant, and Fire Protection Applications, Final Report to the Alliance for Responsible Atmospheric Policy, March 21, 2002.
[14] U.S. High GWP Emissions 1990-2010: Inventories, Projections and Opportunities for Reductions, EPA 000-F-97-000, June 2001.
[15] U.S. High GWP Emissions 1990-2010: Inventories, Projections and Opportunities for Reductions, EPA 000-F-97-000, June 2001.
[16] Arthur D. Little, Inc., Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant, and Fire Protection Applications, Final Report to the Alliance for Responsible Atmospheric Policy, March 21, 2002.
[17] Dave Godwin, USEPA, personal conversation, May, 2006.
[18] All data in this section were obtained from the ARMINES interim contract report and slides, presented to ARB in 12/07.

IV. Availability and Technological Feasibility

Direct Emissions Reduction, Retail Food Systems

The technologies required for leak reductions from retail food systems include the following: sensitive leak detection equipment, fixed leak detection methods (optional but useful), utilizing brazed (welded) joints instead of flanged or threaded (mechanical) joints, compressor vibration reduction, and improved or reduced numbers of Schrader valves. Additionally, owners and operators of retail food systems should adopt general policies to have full accessibility to all refrigerant pipe work as this has not been addressed in the past.

Advanced retail food refrigeration designs serve to reduce refrigerant charge (which is important in case of ruptures) as well as reducing leaks through shorter lines that employ fewer fittings. Energy efficiencies of advanced designs in some instances are higher than those of conventional DX systems, but are generally achievable through evaporative heat rejection (evaporative condenser or cooling tower), which can also be applied to conventional DX systems instead of air-cooled condensers[19].

Technologies involved in advanced-design retail food refrigeration systems include distributed systems, secondary loop systems, and reduced charge DX systems.

Distributed systems[20] (or distributed compressor systems) are comprised of several small compressor racks that are located in cabinets that are distributed throughout the store and close-coupled to the display case lineups or storage rooms they serve. With this approach, the long lengths of piping needed to connect the cases with large remote compressor racks in a machine room are eliminated. The cabinets may be placed either at the end of a case lineup on the sales floor or behind the cases around the perimeter of the store. The refrigerant charge requirement for the distributed system is much less than for multiplex systems due to the shortening of the suction and liquid lines to the display cases. With a secondary loop for heat rejection, the refrigerant charge required for a distributed system is about 30-35% of that required for multiplex systems; if separate rooftop condensers are used for each cabinet, the total charge requirement will be about 50-60% that of multiplex systems. Another estimate of distributed system charges is 25% of DX system charges[21].

Secondary loop (SL) systems[22] have the advantage of reduced refrigerant charge and potential for utilization of low-GWP refrigerants (such as ammonia).

[19] Van D. Baxter, Oak Ridge National Laboratory, IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems, Final Report Volume 1 – Executive Summary, April 2003.
[20] Van D. Baxter, Oak Ridge National Laboratory, IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems, Final Report Volume 1 – Executive Summary, April 2003.
[21] Arthur D. Little, Inc., Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant, and Fire Protection Applications, Final Report to the Alliance for Responsible Atmospheric Policy, March 21, 2002.
[22] Van D. Baxter, Oak Ridge National Laboratory, IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems, Final Report Volume 1 – Executive Summary, April 2003.

SL refrigeration systems can take many forms, but they generally employ one or more chillers to refrigerate a secondary fluid that is then pumped to the display cases and storage rooms. Primary refrigerant charge requirement can be reduced to about 10-15% of that needed for conventional direct expansion system. If ammonia is used as the refrigerant, extra safety precautions must be taken in case of ruptures. Another estimate of SL system charges is 11% of DX system charges[23].

Low-charge multiplex systems reduce the overall system refrigerant charge but retain the long connecting lines between compressors and display cases. This can be accomplished by minimizing the refrigerant inventory in the receiver during normal operation (the receiver's primary function in this design is to provide refrigerant storage during system servicing). Total charge required for this system is expected to be about 67% of a conventional multiplex system. Another approach is to reduce charge to the minimum needed for correct operation of the system evaporators. Total refrigerant charge required by this approach is expected to be about 30% of that required by conventional multiplex systems.

Indirect Emissions Reductions, Retail Food Systems
Technologies involved in reducing energy consumption of retail food systems include the following, described in detail elsewhere[24]:

Machine Room Technologies
Evaporative condensers
Floating head pressure controls
Heat recovery
Ambient subcooling
Mechanical subcooling

Display Case Technologies
Add doors to display cases
Energy-efficient reach-ins
High-efficiency evaporator fan motors
Anti-sweat heater controls
Hot gas defrost
Liquid suction heat exchangers
High-efficiency condenser fan motors
High-efficiency compressor systems
Efficient lighting

[23] Arthur D. Little, Inc., Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant, and Fire Protection Applications, Final Report to the Alliance for Responsible Atmospheric Policy, March 21, 2002.
[24] Arthur D. Little, Inc., Energy Savings Potential for Commercial Refrigeration Equipment Final Report, prepared for Building Equipment Division Office of Building Technologies U.S. Department of Energy, June, 1996. Energy savings for machine room vs. display case technologies documented in the Little report, but it is out of date.

Lifecycle Comparison of DX, SL, and Distributed Systems

Total Equivalent Warming Impact (TEWI)

TEWI is a measure of the overall global-warming impact of equipment based on the emissions of greenhouse gases occurring during the operation of the equipment and the disposal of the operating fluids at end-of-life (EOL). TEWI takes into account both direct fugitive emissions, and indirect emissions produced through the energy consumed in operating the equipment. TEWI is measured in units of mass of CO2 equivalents.

Life Cycle Climate Performance (LCCP)

LCCP is also a measure of the overall global-warming impact of equipment based on the emissions of greenhouse gases over its entire life cycle. LCCP is an extension of TEWI, which also takes into account the emissions arising during high-GWP GHG manufacturing.[25]

Comparison of Alternative Technologies[26]

When retail food refrigeration systems are compared in terms of TEWI, it is apparent that about 50% lifecycle CO_2 emissions are due to refrigerant losses, in systems utilizing the most common HFC refrigerants. SL and distributed systems result in much lower direct emissions than DX systems, and slightly higher indirect emissions, the net result being that total warming impact is reduced by approximately 40%.

[25] The major difference between LCCP and TEWI is that LCCP includes the energy and emissions associated with fluorochemical production, whereas TEWI does not (Arthur D. Little, Inc., Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant, and Fire Protection Applications, Final Report to the Alliance for Responsible Atmospheric Policy, March 21, 2002).

[26] IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems, Van Baxter, Oak Ridge National Laboratory, April, 2003.

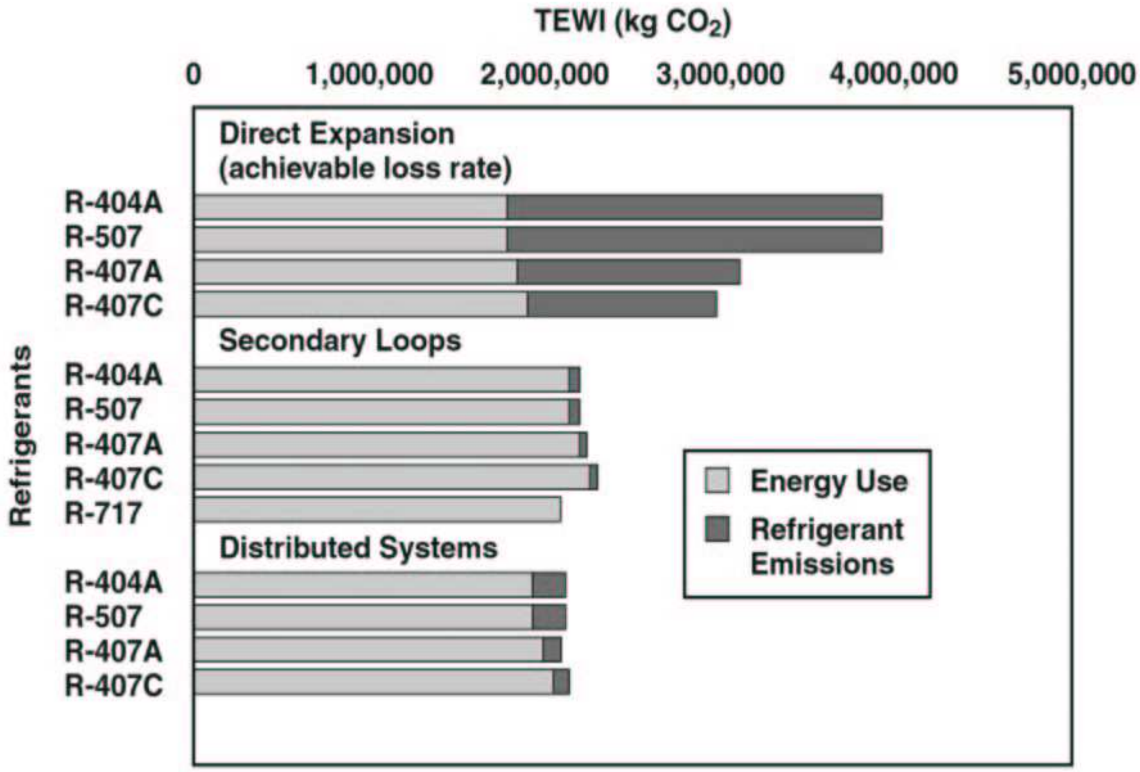

Figure 1. Total Equivalent Warming Impact (TEWI) for Low Temperature Supermarket Refrigeration in North America[27]

<u>Alternative Refrigerants for Commercial Refrigeration Systems</u>
Alternative refrigerants for centralized systems include ammonia and CO_2, although modified system configurations are needed. Note that there is currently very little commercialized use of CO_2 in retail food refrigeration systems.

Due to significant safety concerns, ammonia and hydrocarbons should only be used in a centralized system located in an equipment room with appropriate safety features, with the refrigeration capacity delivered by a secondary heat transport fluid (i.e. SL system).

For standalone equipment, the use of CO_2 is feasible and has been demonstrated since 2004, however, higher operating pressures are required and the energy consumption may be higher than that of conventional standalone equipment.[28]

V. Possible Ideas for Reducing GHG Emissions

<u>Direct Emissions Reduction</u>

[27] IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems, Van Baxter, Oak Ridge National Laboratory, April, 2003.
[28] Sanyo unveiled two-stage rotary CO_2 compressors for commercial vending machines in 2004.

One concept would be to require new retail food systems to adopt secondary loop designs with automatic leak detection systems and low-GWP refrigerants (such as ammonia or CO_2). ARMINES estimates that adoption of SL technology with low-GWP refrigerants will result in direct emissions reductions of about 4 MMT CO_2E relative to BAU in 2020. SL systems with conventional refrigerants are expected to yield reductions of about 3.2 MMT CO_2E relative to BAU in 2020.

The most important feature of SL systems with alternative refrigerants is that in addition to reduced leaks, the potential emissions associated with ruptures are greatly reduced since both the charge size and GWP of the charge are greatly reduced.

Indirect Emissions Reduction Recommendations

Concepts for energy conservation include both machine room improvements (floating head pressure controls) and closed cases for both existing and new systems.

ARMINES estimates that for all supermarkets in California, the maximum energy savings are 30% below baseline (3.7 TWh/yr total energy consumption compared to the baseline of 5.3 TWh/yr) when the above technical options are applied.

Additionally, adopting commercially available, energy-efficient auxiliary components (fans, anti-sweat heaters, lights, etc.) will lead to further indirect emissions reductions.

VI. Cost Information

All leak reduction and energy efficiency improvement technologies appear to be proven and commercially available. For example, Wal-Mart has employed advanced design refrigeration systems (secondary loop with heat reclaim) as well as many of the energy saving devices described in the previous section (LED lighting, closed cases, motion detection for lighting, machine room improvements) with aggressive energy efficiency goals of 25-30% reductions in 4 years.

USEPA and Oak Ridge National Lab estimate that for a SL system with HFC refrigerant, installation costs will be 20% higher baseline DX system; using ammonia refrigerant results in installation costs 75% higher than the baseline case, due to additionally safety features.[29]

It is anticipated that the average baseline DX systems cost approximately $500,000 and that the “average” advanced design costs 20% more to install

[29] U.S. High GWP Emissions 1990-2010: Inventories, Projections and Opportunities for Reductions, USEPA 000-F-97-000, June 2001; Van D. Baxter, Oak Ridge National Laboratory, IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems, Final Report Volume 1 – Executive Summary, April 2003.

($100,000 incremental increased cost).[30] Cost savings will result from energy savings; future energy costs are unknown, but are predicted to increase. Ongoing maintenance costs are unknown, but no incremental increase is expected over baseline systems, especially if continuous monitoring is implemented with indirect systems, which will enable easy and fast leak repair, as well as reduced refrigerant purchases.[31] The cost of enforcement, to ensure compliance, is unknown.

Cost-effectiveness and payback period need closer examination, but staff believe that the emission reduction strategies will be cost-effective when implemented.

VII. Outstanding Questions/Barriers/Issues

One outstanding issue for existing systems is whether and when to require upgrading to new, more energy efficient components or closed cases. Mandatory upgrading could be done on a regulatory timeline, or, since the lifetimes of cases and standalone equipment are short relative to DX system lifetimes (5-10 years compared to 15 or more years), energy-efficient upgrades could be required when equipment needs routine replacement. Additionally, costs and benefits of the regulatory concepts need further evaluation. ARB encourages the expertise and input of all stakeholders to help determine answers to outstanding questions and issues.

VIII. Key Stakeholders

A partial list of trade associations potentially impacted by future regulations follows: the Alliance for Responsible Atmospheric Policy (ARAP), the Air-Conditioning and Refrigeration Institute (ARI), ASHRAE, North American Technician Excellence (NATE), California Grocers Associations, other food-processing or retail-food trade associations, refrigeration equipment trade associations and contractors.

Coordination with US EPA and the California Energy Commission (CEC) with respect to this regulation is ongoing.

IX. Citations

The following references were utilized in addition to those already cited within the body of the document:

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[30] U.S. High GWP Emissions 1990-2010: Inventories, Projections and Opportunities for Reductions, USEPA 000-F-97-000, June 2001; Van D. Baxter, Oak Ridge National Laboratory, IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems, Final Report Volume 1 – Executive Summary, April 2003.

[31] Dave Godwin, USEPA, personal conversation, 2/08.

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